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Proximity effects in superconducting triplet spin-valve F2/F1/S

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ABSTRACT

We investigate the critical temperature T_c of F2/F1/S trilayers (Fi is a ferromagnetic metal and S is a singlet superconductor), where the long-range triplet superconducting component is generated at noncollinear magnetizations of the F layers. In this paper we demonstrate a possibility of the spin-valve effect mode selection (standard switching effect, the triplet spin-valve effect or reentrant $T_c(\alpha)$ dependence) by the variation of the F2/F1 interface transparency.

1. Introduction

We investigate the critical temperature T_c of F2/F1/S trilayers (Fi is a ferromagnetic metal, S is a singlet superconductor), where the long-range triplet superconducting component is generated at noncollinear magnetizations of the F layers [1]. An asymptotically exact numerical method is employed to calculate T_c as a function of the trilayer parameters, in particular, mutual orientation of magnetizations and F2/F1 interface transparencies. Earlier, we demonstrated that T_c in such structures can be a nonmonotonic function of the angle α between magnetizations of the two F layers [2,3]. The minimum is achieved at an intermediate α, lying between the parallel (P, $\alpha=0$) and antiparallel (AP, $\alpha=\pi$) cases. This implies a possibility of a “triplet” spin-valve effect: at temperatures above the minimum T_c^{TR} but below T_c^{P} and T_c^{AP}, the system is superconducting only in the vicinity of the collinear orientations. At certain configuration of parameters, we predict a reentrant T_c behavior. At the same time, considering only the P and AP orientations, we find that both the “standard” ($T_c^P<T_c^{AP}$) and “inverse” ($T_c^P>T_c^{AP}$) switching effects are possible depending on parameters of the system. It was shown recently [4] the existence of the anomalous dependence of the spin-triplet correlations on the angle α in F/F/S structures. In this paper we demonstrate a possibility of the spin-valve effect mode selection (standard switching effect, the triplet spin-valve effect or reentrant $T_c(\alpha)$ dependence) by the variation of the F2/F1 interface transparency.

2. Results and discussion

To prove this statement we calculate the critical temperature of F2/F1/S structure (see Fig. 1) for arbitrary values of the angle α and F2/F1 interface transparencies.

We suppose that F metals are monodomain ferromagnets with generally different values of the exchange field energy, H_{F1} and H_{F2}. We also assume that interfaces are not magnetically active and can be described by the spin independent suppression parameters γ and γ_B [5]

$$\gamma_{BF1S}=R_{BF1S}\mathcal{A}_B/\rho_{F1}\xi_{F1},\quad \gamma_{F1S}=\rho_S\xi_S/\rho_{F1}\xi_{F1},\tag{1}$$

$$\gamma_{BF2F1}=R_{BF2F1}\mathcal{A}_B/\rho_{F2}\xi_{F2},\quad \gamma_{F2F1}=\rho_{F1}\xi_{F1}/\rho_{F2}\xi_{F2},\tag{2}$$

where R_{BF1S}, R_{BF2F1} and $\mathcal{A}_B$ are the resistance and the area of the F1S and F2F1 interfaces; $\rho_{S(F1,F2)}$ is the resistivity of the S(F1,F2) layer and the coherence lengths are related to the diffusion constants $D_{S(F1,F2)}$ as $\xi_{S(F1,F2)}=\sqrt{D_{S(F1,F2)}/2\pi T_{cS}}$ (T_{cS} is the critical temperature for an isolated superconductor). For simplicity, we also suppose that conditions of dirty limit are fulfilled for all the films. Under the above assumptions, we can use the following linearized Usadel equations [1,6]:

$$\xi_{F2}^2\frac{d^2}{dx^2}f_0-\Omega f_0+ih_{F2}f_3=0,\tag{3}$$

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